PERFORMANCE OF OPTICAL FIBERS FOR REFERENCE FREQUENCY AND IF SIGNAL TRANSMISSIONS IN VLBI OBSERVATION

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Abstract

We have constructed a 6 m antenna system in the Nobeyama Radio Observatory (NRO) complex of the National Astronomical Observatory, Japan. This system is used for the International Radio Interferometric Surveying trans–Pacific (IRIS–P VLBI) network observation of the International Earth Rotation Service with the Mark–111 VLBI Back–end and the hydrogen maser frequency standard operating at the control room of the 45 m antenna in the NRO. This 6 m antenna is located about 880 m apart from the control room. Therefore, the 10 MHz reference frequency signal and the IF signals should be transmitted over 880 m distance without signal phase fluctuations in the Mark–111 VLBI observations. The phase stabilized signal transmission should be attained by using phase stabilized optical fiber (PSOF). Prior to introduction of this system, we have made a phase stability estimation by experiments.

The PSOF is currently developed at Sumitomo Electric Industries, Ltd. of Japan. We have tested the prototype of this PSOF signal transmission system of which the length is 1000 m. The phase stability of the 1000 m PSOF system is 3.95×10^{-15} **(t=1000 sec.) in Allan standard deviation (ASD) at the stabilized temperature of** 21.4 °C ± 0.5°C **and at the frequency of 20.9 MHz. The stability is about 55 times better than the ordinary coaxial cable transmission system. In the environment of temperature variation of** +30 °C, **the stability of this PSOF is** 1.97×10^{-14} **(t=1000 sec.) in ASD.**

INTRODUCTION

A group for a 6 m antenna construction project in Division of Earth Rotation of National Astronomical Observatory has currently constructed the 6 m antenna VLBI system which uses the Mark–111 back–end in NRO complex. This system will be used for the IRIS–P VLBI network observation of an International Earth Rotation Service. The Mark–III VLBI Back–end was originally installed as the back–end of the 45 m antenna in the NRO. The location of the 6 m antenna is about 880 m apart from the control room of the 45 m antenna where the Mark–111 back–end is installed.

The correlation amplitude in a VLBI correlation observation is dependent on the antenna diameter, the system noise and coherence factor. The coherence factor of the VLBI observation is influenced from a stability of a reference frequency signal. Our 6 m antenna is small in diameter and this small

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diameter is a large factor in decreasing the correlation amplitude. We could not install a preamplifiers which have sufficiently low noise due to some limitations. So, we tried to maintain the coherence due to the phase fluctuations of the reference frequency signal and IF signal transmission lines as small as possible to obtain enough correlation amplitude.

Phase stability measurement of a coaxial cable and phase stabilized optical fiber (PSOF) signal transmission systems was made to examine these systems can satisfy our requirement. In this paper, we will report the result of the measurements obtained in the laboratory at the National Astronomical Observatory (NAO) Mizusawa and in the NRO where the PSOF is actually installed in the underground tunnel for VLBI observations.

TOLERANCE OF PHASE FLUCTUATIONS

To obtain a moderately large correlation amplitude in the VLBI observation using the 6m antenna system, we have decided maintain the coherence loss due to the phase fluctuations as small as 2%. It means the limitation of the phase variation of 5 MHz reference frequency should be 0.01 ° rms when the noise is assumed to be white phase. In general, a phase variation $< \Delta\phi^2 >^{1/2}$ is expressed as

$$< \Delta\phi^2 >^{1/2} = \left[\frac{2}{3}\sigma_y^2(\tau)\right]\omega\tau \tag{1}$$

in Allan variance σ_y^2 when the noise is white phase and τ is integration time[1]. Or, one can write

$$\sigma_y^2(\tau) = \frac{3}{2}\left[< \Delta\phi^2 >^{1/2} /(\omega\tau)\right]^{1/2}. \tag{2}$$

In the case of $f = 5 \times 10^6$ Hz, $\tau = 0.1$, 10, 1000 seconds, $\Delta\phi = 0.01°$, we have Allan standard deviation (See Table 1).

PHASE STABILIZED OPTICAL FIBER

An ordinary optical fiber has positive thermal expansion coefficient and it causes transmission time delay in proportion to a temperature when this kind of optical fiber is used for signal transmission. The normal optical fiber has a silica fiber in the center and this silica fiber is coated twice. The primary coating is a kind of an absorber for a friction between the center silica and secondary coating which is crust. Sumitomo Electric Industries has currently developed PSOF which uses liquid crystal polymer (LCP) for the secondary coating[2]. The LCP has a negative thermal expansion coefficient and compensates the positive thermal expansion coefficient of the center silica fiber. The change of transmission delay time of this PSOF is 100ps/km in the temperature range of -40 °C $\rightarrow$ $+40$ °C.

MEASUREMENT SYSTEM FOR PHASE STABILITY EVALUATION

Time domain measurements of frequency stability have been made to obtain the ASD. A dual mixer time domain (DMTD) system was used for these measurements[3]. We used a delay calibrator (D–cal) of the Mark–III VLBI back–end in which both a 5 MHz reference signal and a 5 MHz test signal are

mixed down to 25 Hz and the time interval between these two 25 Hz output signals from the D–cal is measured. Two types of these DMTD system was made. One of these systems is for the measurement of the frequency for 5 MHz and the other is the double conversion system for 20.9 MHz or 150.9 MHz measurement. Figures 1, 2 and 3 show the block diagrams of these DMTD systems.

RESULTS OF THE MEASUREMENTS

The phase stability of PSOF with the length of 1 km has been measured at 5 MHz in the laboratory. And the phase stability of RG–213/U coaxial cable with the length of about 490 m which is installed most of the part in a trench is also measured at the frequency of 5 MHz. The depth of the trench is about 50 cm and the temperature fluctuation in the trench is expected as ±0.4 °C/hour in December at this depth. The results of these measurement is shown in figure 4. From this measurement, we conclude the phase stability of PSOF is about 55 times better than that of coaxial cable. A frequency dependency of the phase stability was found out for the PSOF in this measurement as shown in figure 4. Extra measurement for an effect of a fiber distortion was made to make clear this frequency dependency. From the figure 5, it is considered that the origin of this frequency dependency is the distortion caused by the optical fiber. The distortion effect is considered to be caused by the modulation of a signal by a reflected light signal in the fiber cable. It is recommended that the use of the frequency over 10 MHz for less distortion effect from the figure 5. And an isolator in a optical fiber line will help to eliminate this frequency dependency[4]. In our case, however, no isolator for the reflected signals was used and the optical fibers were installed without any distortion due to antenna's motion. A coaxial cable was used for the part of the inside of the antenna. The phase stability of this PSOF at various environment temperature was measured at 20.9 MHz so that the distortion effect on the fiber was smaller. The results of the measurement are shown in figure 6. The phase of the PSOF is stable enough in the environment temperature change below +6 °/hour. From the figures 4 and 6, we have decided to use the PSOF's for the reference frequency and IF signal transmission lines of 6 m antenna system.

The specifications of the signal transmission system (PSOF system) which uses PSOF are shown in Table 2. We have measured the phase stability of the installed PSOF system at NRO using the same component used for the laboratory measurement at the frequency of 5 MHz and 150.9 MHz. The figure 7 shows the result of this measurement. The temperature fluctuations of the tunnel which was designed for the 5 element interferometer using 10 m antennas at the NRO is considered to be very small. The PSOF systems for 6 m antenna are installed in this tunnel and very high phase stability is expected even for ordinary coaxial cable because the tunnel is designed to stabilize the phase of transmission signal in coaxial cables. So, the results of the phase stability measurement for 1760 m round trip (880 m one way) coaxial cable is very stable compared to the result of the 490m coaxial cable in the environment temperature ±0.4 °/hour shown in figure 4. Even though, the PSOF system is more stable than coaxial cable at 5 MHz but the ratio of the stability is not 55, because the frequency dependency which mainly caused by reflection of a light in a fiber affects more strongly at lower frequency such as 5 MHz. The result of the measurement at 20.9 MHz in the laboratory is also plotted in the figure 7. These result of the measurement made at 20.9 MHz in the laboratory is considered to be almost the same as the result of the PSOF system installed for 6 m antenna because environment temperature variation for the measurement of the installed PSOF system at NRO seems to be almost the same environment as the laboratory. The plots of 5 MHz, 20.9 MHz and 150.9 MHz in figure 7 follow the characteristics of the frequency dependency shown in figures 4 and 5. The reference frequency which is transmitted through this PSOF system is 10 MHz for 6 m antenna system. Assuming that the phase stability of 10 MHz is almost the same as 20.9

MHz, we conclude that the PSOF system does not exceed the phase stability tolerance for coherence loss of 2% when introduced to the 6 m antenna system at 1O MHz for the distance over 1700m. And the stability of the PSOF system at 1O MHz is about 2.2 times lower than that of coaxial cable even in the condition of temperature stabilized environment carefully designed for the 5 element mm wave length interferometer.

CONCLUSION

The PSOF is used for 1O MHz reference frequency transmission of which the distance is over 880 m in 6 m antenna system without exceeding the tolerance of phase stability estimated for coherence loss of 2%. The PSOF is also used for wide band (100–52O MHz) IF signal transmission of which the distance is over 880 m in this 6 m antenna system without a loss of a signal power. This IF signal transmission system does not require the frequency response equalizer which usually degrades a phase stability and is required for a coaxial cable system.

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Table 1. Tolerance of Phase Stability for VLBI Observations which has coherence loss of 2 % for X-band observation with integration time of 800 seconds.

Integration Time	Allan Standard Deviation $<\sigma_y^2>^{1/2}$
0.1	6.8×10^{-11}
10	6.8×10^{-13}
1000	6.8×10^{-15}

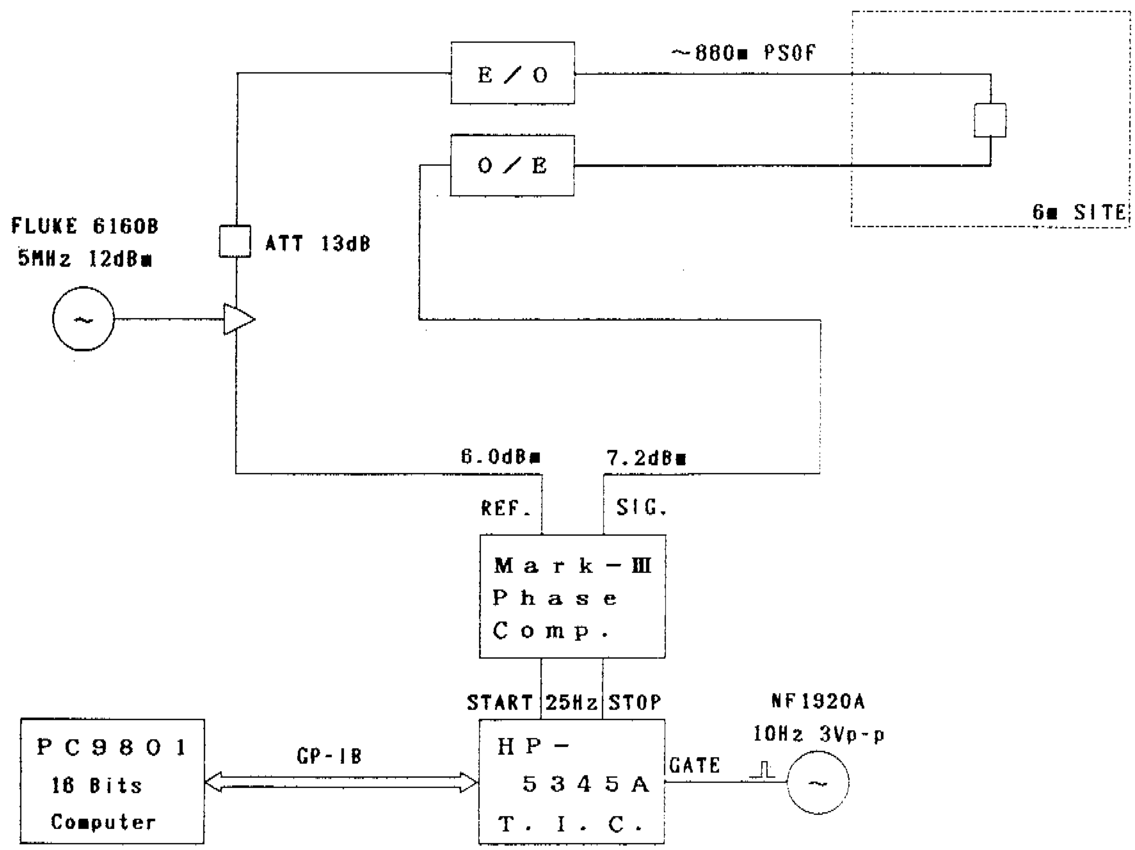

Figure 1. The block diagram of the Dual Mixer Time Domain (DMTD) system for the phase stability measurement. This system is used for the measurement of the installed PSOF at NRO. The frequency of this system is 5MHz.

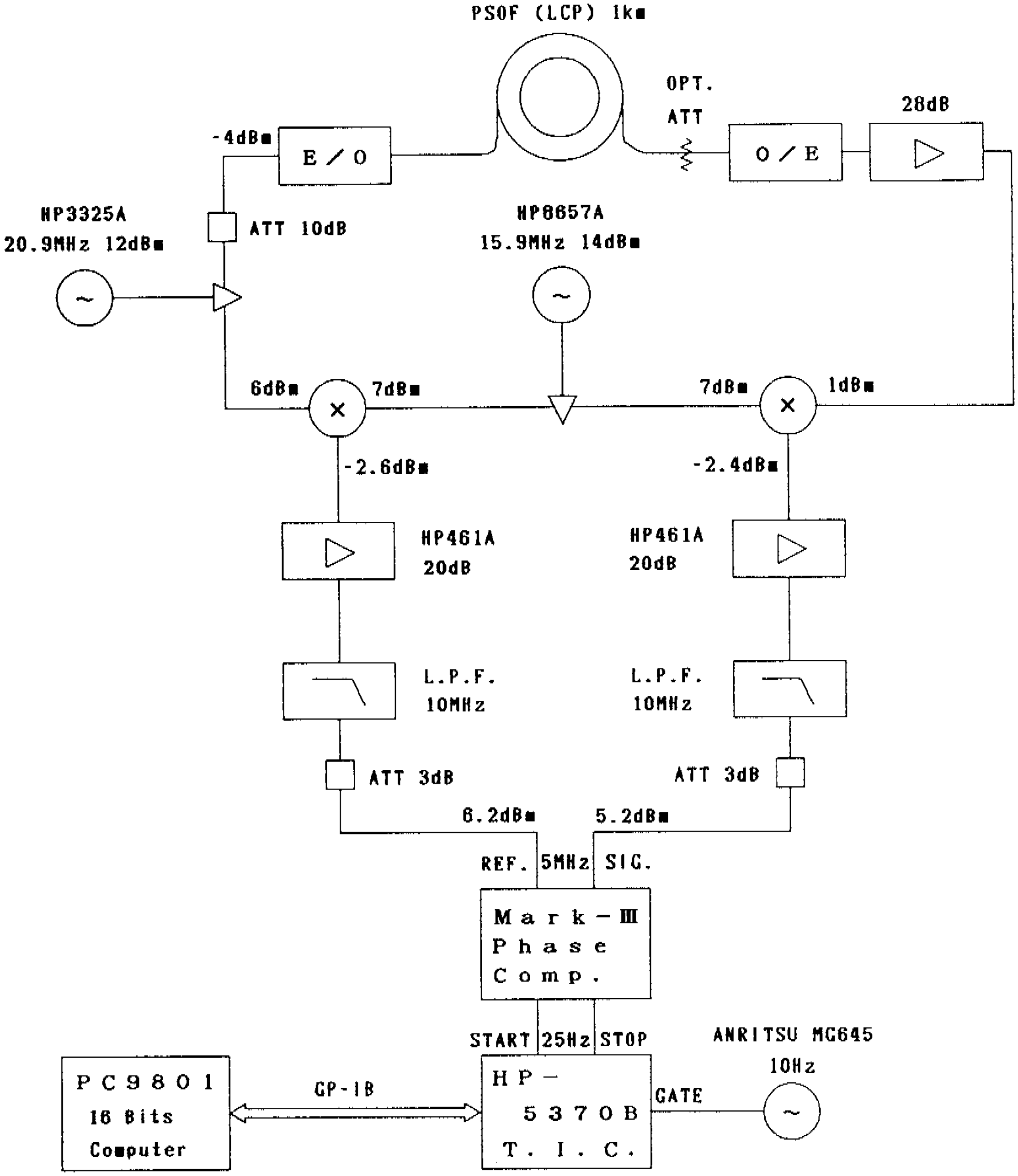

Figure 2. The block diagram of the Dual Mixer Time Domain (DMTD) system for the phase stability measurement. This system is used for the measurement of 1km PSOF in the laboratory. The frequency of this system is 20.9MHz.

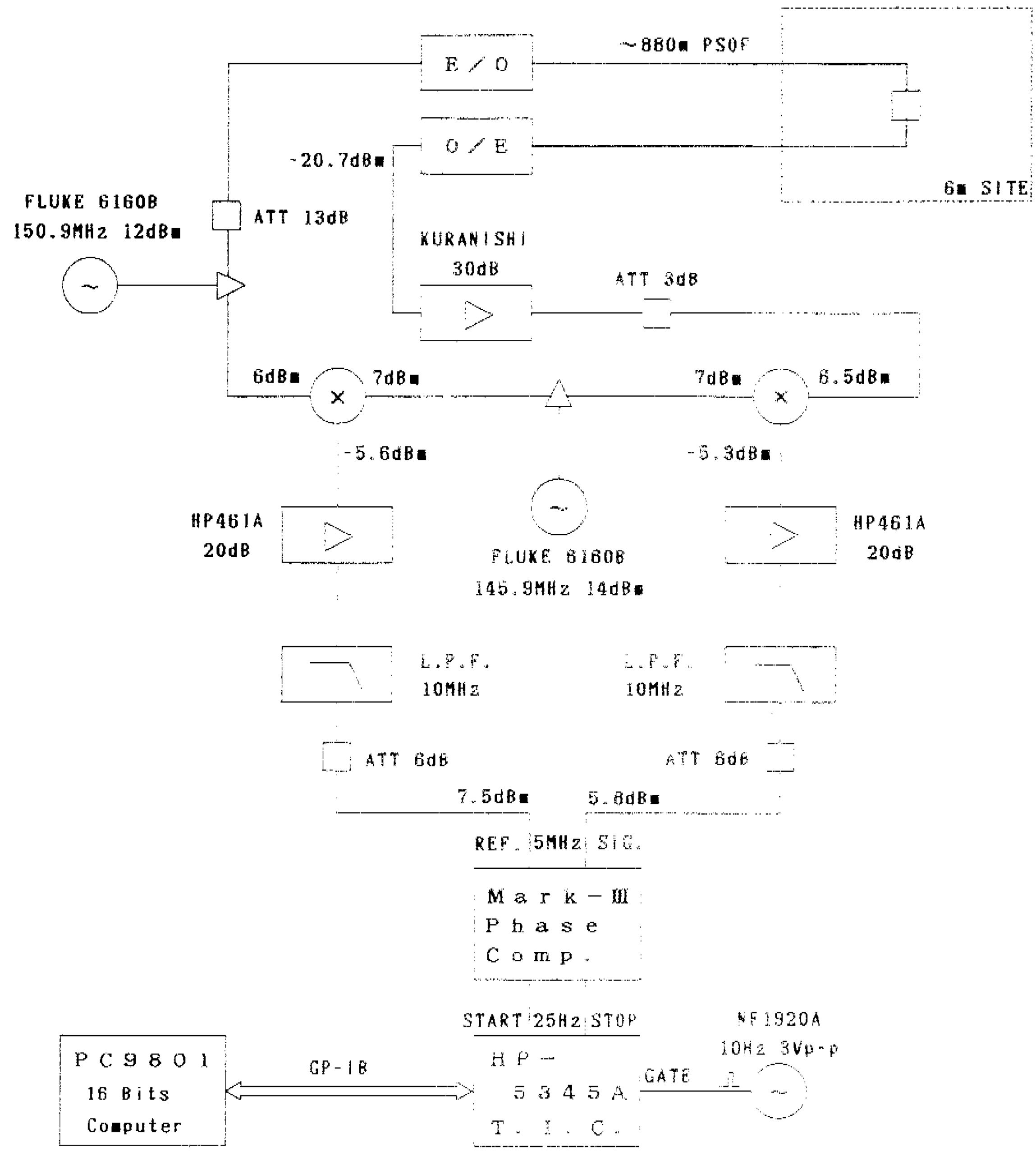

Figure 3. The block diagram of the Dual Mixer Time Domain (DMTD) system for the phase stability measurement. This system is used for the measurement of the installed PSOF at NRO. The frequency of this system is 150.9MHz.

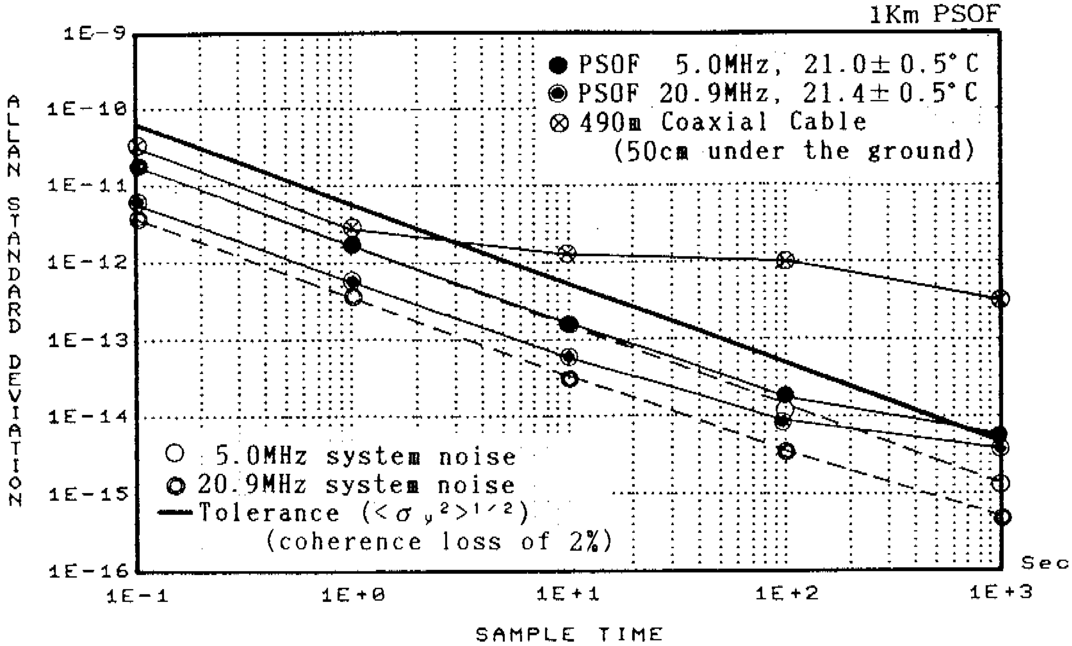

Figure 4. The Allan standard deviation of the 1km PSOF and coaxial cable laid 50cm under the ground. All these measurement had been obtained in a Laboratory

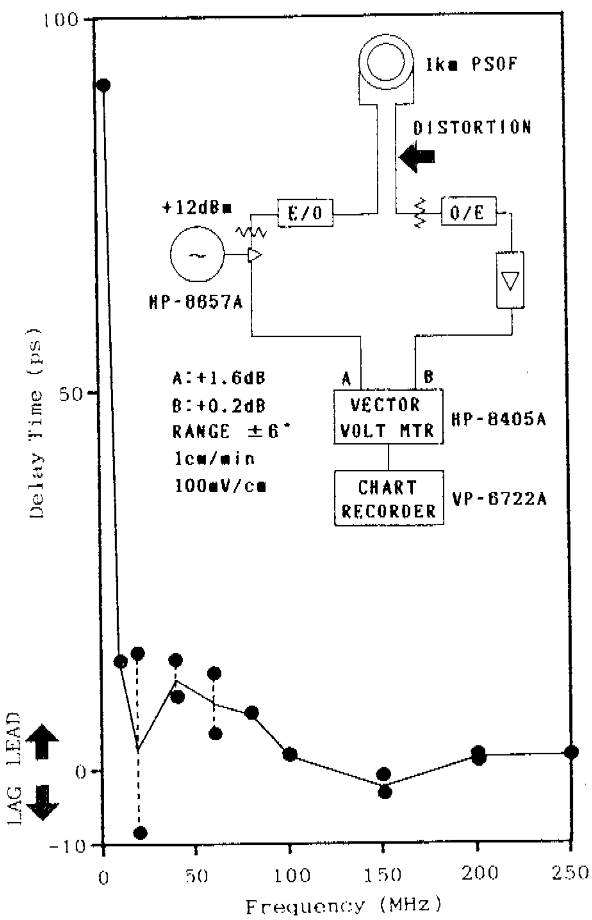

Figure 5.
The frequency dependency of transmission delay time in the condition of a distortion is inflicted to the optical fiber. The block diagram of this measurement system is also shown in this figure.

Table 2. Specifications of Optical Transmitter and Optical Receiver for PSOF

CMT-50 (1MHz～50MHz) Transmitter	
Bandwidth	1～50MHz at gain flatness <±1dB
Optical output level	>-2dBm (mean value)
Electrical input level	-5～-30dBm at 50 ohm load
Phase noise	<-80dBc at 100Hz offset
Phase stability	<2°rms in 10 minutes
2nd harmonics	<-30dB
CMR-50 (1MHz～50MHz) Receiver	
Bandwidth	1～50MHz at gain flatness <±1dB
Optical input level	>-10～-20dBm (mean value)
Electrical output level	+10～-20dBm (50 ohm & opt -10dBm)
Phase noise	<-80dBc at 100Hz offset
Phase stability	<2°rms in 10 minutes
2nd harmonics	<-30dB
CMT-500 (100MHz～520MHz) Transmitter	
Bandwidth	100～520MHz at gain flatness <±1dB
Optical output level	>-2dBm (mean value)
Electrical input level	-5～-30dBm at 50 ohm load
Phase noise	<-80dBc at 100Hz offset
Phase stability	<2°rms in 10 minutes
2nd harmonics	<-30dB
CMR-500 (100MHz～520MHz) Receiver	
Bandwidth	100～520MHz at gain flatness <±1dB
Optical input level	>-10～-20dBm (mean value)
Electrical output level	-5～-35dBm (50 ohm & opt -10dBm)
Phase noise	<-80dBc at 100Hz offset
Phase stability	<2°rms in 10 minutes
2nd harmonics	<-30dB

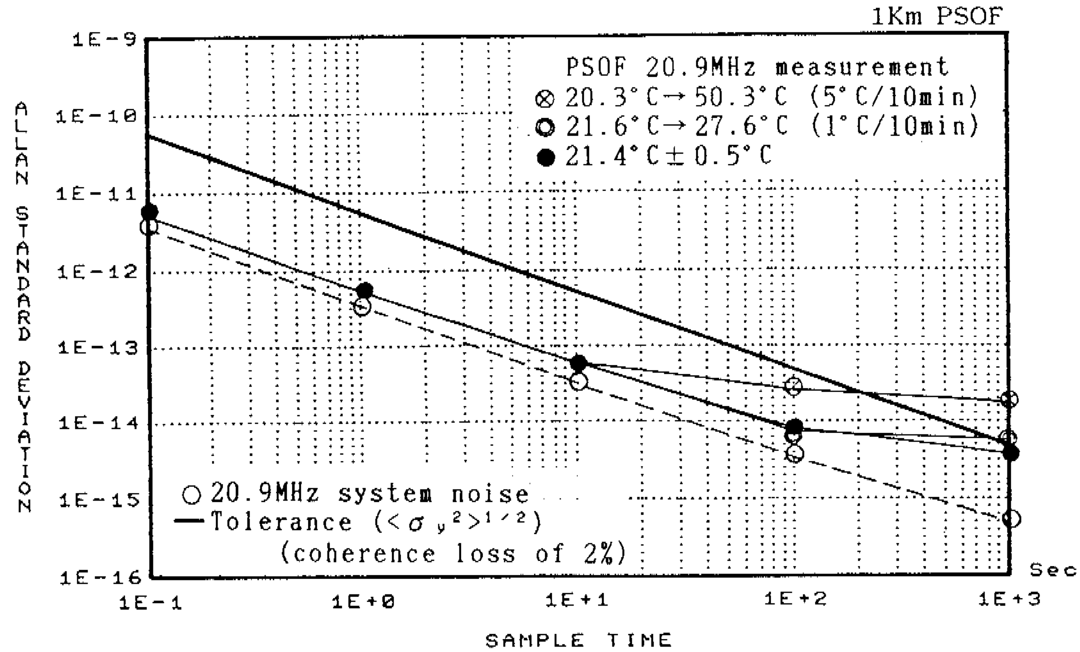

Figure 6. The Allan standard deviation of the 1km PSOF in environment temperature fluctuation. The measurement had been obtained in a laboratory.

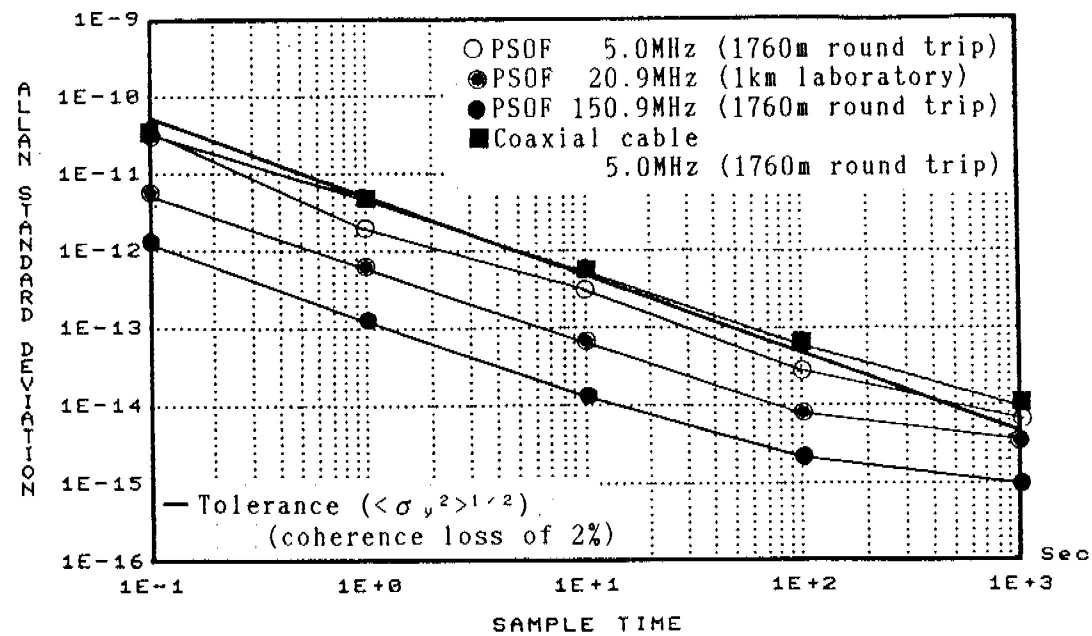

Figure 7. The Allan standard deviation of the 880m PSOF's and the coaxial cable installed in the tunnel at NRO for 6m antenna system. The temperature in the tunnel is well stabilized and even the coaxial cable has good phase stability. The phase stability of PSOF is remarkably better than the stability of the coaxial cable.